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STUDY TO DEFINE LOW VOLTAGE AND
LOW TEMPERATURE OPERATING LIMITS OF THE PIONEER 10/11
METEOROID DETECTION EQUIPMENT (MDE) SYSTEM

FINAL REPORT

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A B S T R A C T

The Pioneer 10/11 Meteoroid Detection Equipment (MDE) pressure cells were tested at liquid nitrogen (LN_2) and liquid helium (LHe) temperatures with the excitation voltage controlled as a parameter. The cells failed by firing because of pressurizing gas condensation as the temperature was lowered from LN_2 to LHe temperature and when raised from LHe temperature. A study was conducted to determine cell pressure as a function of temperature, and cell failure was estimated as a function of temperature and excitation voltage. The electronic system was also studied and a profile of primary spacecraft voltage (nominally 28 Vdc) and temperature corresponding to electronic system failure was determined experimentally.

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PIONEER MDE TRANSDUCER EXPERIMENT

The Pioneer MDE transducers were previously characterized at the temperature of liquid nitrogen (LN₂), -195.8°C. The low temperature tests described herein were conducted at the temperature of liquid helium (LHe), -268.9°C, because it is a convenient temperature for these tests and, if successful, would demonstrate the Pioneer MDE transducer and gas to be suitable to the lowest possible test temperature. Cryogenic properties of argon, helium, and nitrogen, which are of interest in this report, are tabulated in Table I.

Description of Apparatus and Procedure

The low temperature test apparatus is illustrated in Figure 1. The test transducer was mounted at the end of a section of stainless steel tubing with an outside diameter of approximately 6.4 mm. (The tubing, transducer, and two electrical leads had to pass through a small opening in the top of the cryostat.) The opposite end of the tubing was terminated in a variable leak valve (Granville-Phillips Company Series 203). A sintered stainless steel filter was located at the inlet to the variable leak valve to protect the valve, and the filter was connected through a "tee" connector to two vacuum quality valves which served to isolate the transducer, filter, and variable leak valve. One vacuum valve, valve 1, was connected to an MDE gas source; and a second, valve 2, was connected to a vacuum pump. The tubing containing the transducer was 4 feet long so that the "test cell" could be lowered to near the bottom of the LHe cryostat. Tubing between the variable leak valve and the two vacuum quality valves was as short as possible to keep the volume isolated when valves 1 and 2 were closed to a minimum. The long, flexible lines extending from valves 1 and 2 permitted the tubing housing the transducer to be raised above the cryostat, guided to the cryostat opening, and lowered into the liquid helium. When the vacuum valves in Figure 1, valves 1 and 2, are closed, the volume isolated between the valves, including the filter and variable leak valve, is estimated to be $26 \times 10^{-3} \text{ m}^3$.

TABLE I

SOME CRYOGENIC PROPERTIES OF ARGON, HELIUM, AND NITROGEN			
Property	A	N ₂	He
Atomic or Molecular Weight	40	28	4
Boiling Point	-185.9°C	-195.8°C	-268.9°C
Melting Point	-189.4°C	-210.0°C	---
Vapor Pressure at LHe Temp.	<1 mmHg	<1 mmHg	---
Triple Point	-189.5°C 517 mmHg	-210.1°C 93 mmHg	

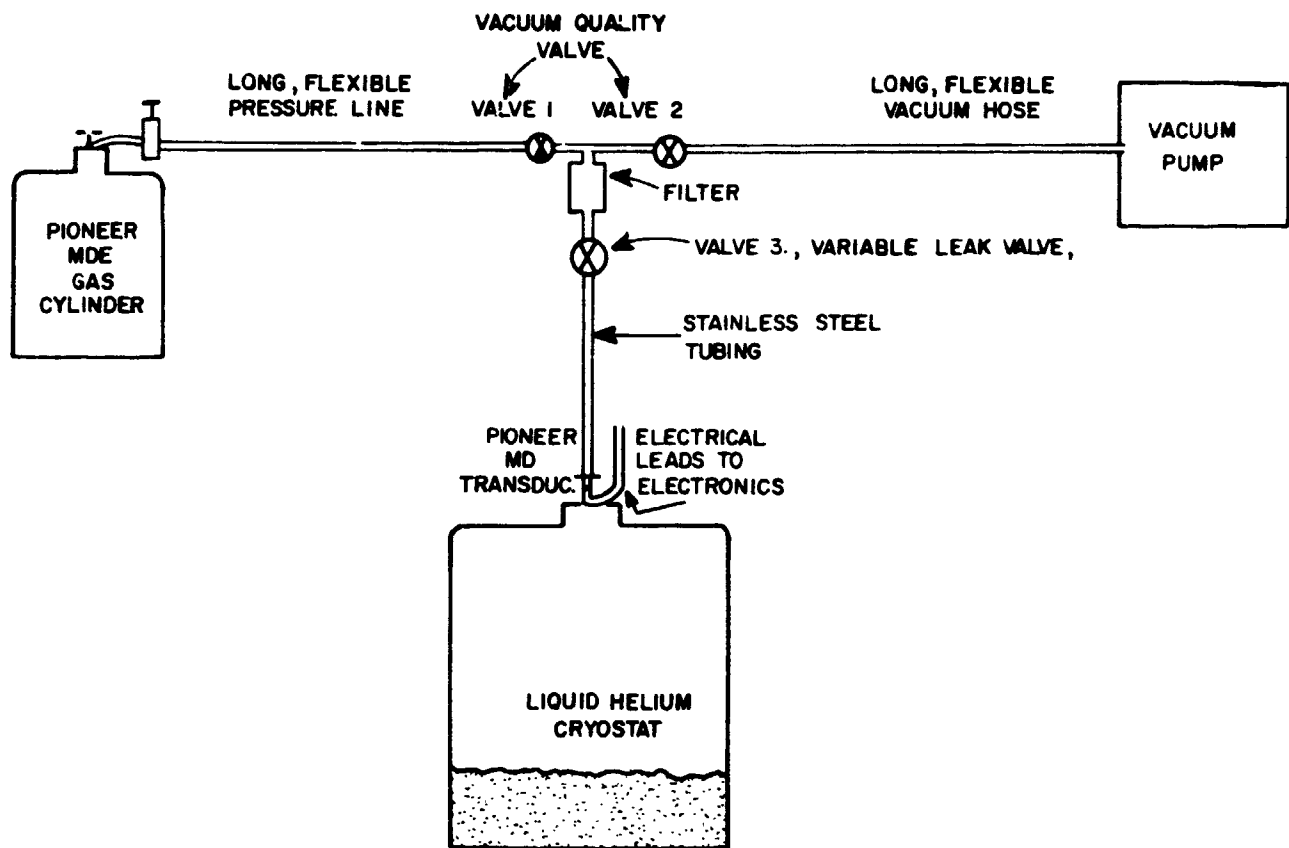


Figure 1. Liquid Helium Temperature Test Apparatus

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The test cell was connected to the circuitry illustrated in Figure 2 which is identical to the Pioneer MDE transducer interface circuitry. Transducer firing events were monitored on a strip chart recorder and an oscilloscope.

Prior to any experimentation, the variable leak valve was set for a slow leak rate and left at that setting throughout the experiment. The rate of flow through the valve was not critical, but was set to insure that the transducer would remain in a pressure range conducive to firing for several minutes. This leak rate was set experimentally during room temperature experiments. In addition to setting the variable leak valve, the pressure regulator on the MDE gas cylinder was adjusted to a pressure of approximately 1000 mmHg which was the approximate sealing pressure of the Pioneer MDE pressure cells.

A typical experimental procedure was as follows. With the transducer at room temperature, the volume between valves 1 and 2, including the variable leak valve and transducer, was pumped to a rough vacuum by closing valve 1 and opening valve 2 to the vacuum pump. Valve 2 was closed, and valve 1 was opened to pressure the transducer region to 1000 mmHg. Valve 1 was then closed to isolate the gas in the volume between valves 1 and 2, i.e., the test cell. The test cell was then lowered into the LHe to reduce the temperature of the transducer and the pressurizing gas. Valve 2 could then be opened to pump the MDE gas from the trapped volume. The variable leak valve restricted the leak to a relatively slow rate which could occur in the Pioneer MDE pressure cells as a result of a meteoroid penetration in space.

Experimental Results

The initial step in the low temperature experiment was to demonstrate that the test cell was typical of the Pioneer MDE pressure cells. Since there were no provisions for monitoring the pressure in the vicinity of the transducer, its characteristics were checked at room temperature by pressurizing the test cell and pumping it to a vacuum through the restricting variable leak valve. This procedure was repeated several times each with different excitation voltages applied to the test cell. The test cell was observed to fire routinely at excitation voltages from -500 Vdc to -250Vdc. At -225 Vdc excitation, a routine firing event was not observed. (The oscilloscope monitor would occasionally trigger, but an output pulse of significant amplitude could not be observed.) Minimum output voltages observed for the different excitation voltages are tabulated in Table II. These results were observed repeatedly.

The test cell was also forced to fire at the sealing pressure (approximately 1000 mmHg) and room temperature by increasing the excitation voltage in decade steps at 5-second intervals until a firing event occurred. Firing events were observed at voltages of 960, 1010, 1030, and 1300 volts. These

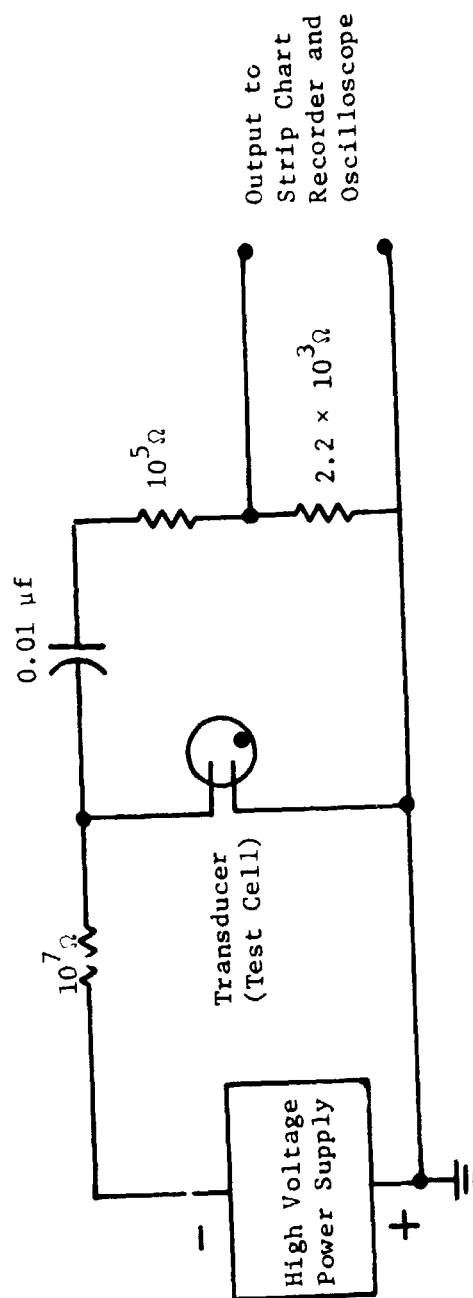


Figure 2. Circuitry for Monitoring the Test Cell

TABLE II
MINIMUM OUTPUT VOLTAGES FOR DIFFERENT EXCITATION VOLTAGES
(20°C)

Excitation Voltage (Volts dc)	Minimum Output Voltage (Volts)
-500	> 4
-400	> 4
-375	> 4
-350	> 4
-325	> 4
-300	> 4
-275	> 3.5
-250	> 2

voltages and the minimum firing voltages observed when the test cell was pumped to a vacuum are indicative of a typical Pioneer MDE pressure cell and would fall in the range of the Paschen characteristics for MDE transducers. (During these room temperature experiments, the variable leak valve was set to 150 and initial firing events occurred in 2 to 3 minutes after opening valve 2.)

The LHe temperature experiments were begun by pressurizing the test cell with the Pioneer MDE gas, i.e., closing valve 2 after evacuating, opening valve 1, and closing valve 1 to isolate the test transducer. The transducer was then lowered into the LHe. The excitation voltage was applied and changed in steps from an initial -400 Vdc to -2000 Vdc. No firing events were observed. The excitation voltage was set to -400 Vdc, and valve 2 opened to evacuate the test cell. Valve 2 was open for approximately 31 minutes, and the excitation voltage was changed from -400 to -800 Vdc during this interim. At 31 minutes, the excitation voltage was changed back to -400 Vdc, and the test cell lifted from the LHe. The test cell quickly began to fire in a manner characteristic of the Pioneer MDE pressure cells at LN₂ temperature and above.

In subsequent experiments, the test cell was pressurized to 1000 mmHg at room temperature and isolated by closing valves 1 and 2. With voltage excitation applied, the cell was observed to fire (and oscillate as is characteristic of the cell in the relaxation oscillator) repeatedly whenever the cell was lowered into the LHe and when removed from the LHe. These observations were repeated at -600, -500, -400, and -350 Vdc. Firing events were not observed when the cell was lowered into LHe or removed from LHe when the excitation voltage was -300 Vdc.

When the cell was lowered into the LHe with voltage excitation, the cell would fire briefly and then cease to fire. If valve 2 was then opened, the cell would usually fire and continue firing for a long period. After firing ceased, no further firing events were observed when the cell was removed from the LHe. There were occasions, however, in which the cell was not observed to fire after opening valve 2 for a significant time period, and it did fire when removed from the LHe with the valve opened.

The results of the low temperature experiments described in the preceding paragraphs suggest the following conclusions. First, the Paschen characteristic minimum for the Pioneer MDE pressure cell at the temperature of LHe lies between -300 and -350 Vdc. Second, the Pioneer MDE cells will fail at some temperature below that of LN₂ and above that of LHe. The failure mode will be extraneous firings. At some lower temperature, the firings will cease.

The following failure mechanism for the test cell identified earlier as a test transducer is hypothesized, and a similar mechanism can be expected for the pressure cells on board Pioneer 10 and Pioneer 11. (A subsequent paragraph will discuss the potential for a significant difference between the test cell and a cell on board Pioneer 10 or Pioneer 11 due to the effect of Earth's gravity.) As the temperature of the test cell is lowered, the pressurizing gases (argon and nitrogen) will eventually liquefy and then solidify. As it liquefies, the pressure in the cell will drop to the sum of the vapor pressures of argon and nitrogen at the temperature of the cell. At the temperature of LHe, for example, the vapor pressures of both argon and nitrogen are less than 1 mmHg. Consequently, as the temperature is lowered, the pressure in the cell will pass through a range at which conduction between the transducer electrodes can occur.

As the temperature of the test cell is lowered by immersing it in LHe, the pressurizing gases are likely to condense on the walls of the cell tubing. If the argon and nitrogen remain as a liquid long enough, and are of sufficient quantity, it is possible for the liquid to flow to the bottom of the tubing, i.e., to the transducer, before freezing to a solid. (The pressurizing gas in the test cell is estimated to be 0.04 liters in the liquid phase.) The "collecting" effect would not be present on the Pioneer spacecrafts because of the absence of Earth's gravity. (A collecting of the liquid gas is also unlikely in the test cell because the amount of liquid is very low and the boiling and freezing temperatures are very close together for both argon and nitrogen.) Because the temperature of the cell is below the triple point temperature of argon (-189.5°C) and nitrogen (-210.1°C), the gas should pass directly from the solid phase to the gas phase when exposed to a vacuum at a lower pressure than the triple point pressure; and, again, the distribution of the solid throughout the cell may have a significant influence on the characteristics of the cell. The rapid transition of the pressurizing gas through three (or two) phases is a dynamic process that, unfortunately, cannot be observed inside the Pioneer MDE cell.

By assuming that the test cell and the Pioneer MDE pressure cells were sealed at 1170 mmHg and at a temperature of 300°K (27°C), and that the volume remains constant, the pressure in the cell and the state or phase of the pressurizing gas can be estimated. These estimates further assume that the pressurizing gas, 75 percent argon and 25 percent nitrogen by volume, conforms to the perfect gas law -- i.e., $PV = nRT$, and nitrogen gas is relatively insoluble in liquid nitrogen.

The vapor pressure data in Figure 3 are essential for estimating cell pressure. Cell pressure as a function of temperature is also plotted in Figure 3 for sealing pressure of 1170 mmHg and 1000 mmHg. These results illustrate that sealing pressure variations have little effect on the cell pressure at low temperatures. The vapor pressure data were taken from Stull (Ref. 1).

At temperatures above 79°K (-195°C), both the argon and nitrogen remain gaseous and cell pressure is given by the sum of the partial pressures of the two gases. Below 79°K (but above 60°K (-213°C)) the argon is in liquid phase (possibly a solid phase), the nitrogen is a gas, and the cell pressure is the sum of the partial pressure of nitrogen and the vapor pressure of argon at the reduced temperature. At 60°K , the partial pressure of nitrogen is approximately the vapor pressure of nitrogen and the nitrogen condenses to a liquid. Below 60°K , the cell pressure is the sum of the vapor pressures of the argon and nitrogen.

Figure 4 is a worst-case, Paschen characteristic curve for the Pioneer MDE pressure cells. This curve was taken from previous experimental results with the Pioneer MDE pressure cell at LN_2 temperature (Ref. 2) and failed on the minimum firing voltage at LHe temperature demonstrated during the low temperature experiments described previously in this report. It is considered to be a worst-case curve because most of the observed data points (>95 percent) would fall above this curve for a given pressure. Moreover, a minimum firing voltage of 350 volts has been demonstrated at LHe temperature, the cells have been demonstrated to be satisfactory at LN_2 temperature, and Paschen curves for temperatures below LN_2 are expected to fall above the curve of Figure 4. For a given excitation voltage, a firing (or failure) pressure can be determined from Figure 4, and this firing pressure can be used to determine the temperature at which a sealed cell will fire in Figure 3. If the excitation voltage is 400 volts, for example, a worst-case firing pressure of 15 mmHg can be estimated from the curve of Figure 4. From Figure 3, this corresponds to a temperature of 55°K (-218°C). Thus, the pressure cells are expected to fail at 55°K due to reduced pressure in the cell. By repeating this procedure, a cell temperature-excitation voltage failure profile was generated, and these results are shown in Figure 5.

It is noted from Figure 3 that for temperatures below 60°K , the cell pressure is approximately equal to the vapor pressure of nitrogen. Consequently, for the failure mode considered in this report, the temperature at which failure occurs is relatively independent of variations in sealing pressure and sealing temperature. As illustrated in Figure 5, the failure temperature is only slightly dependent on the excitation voltage.

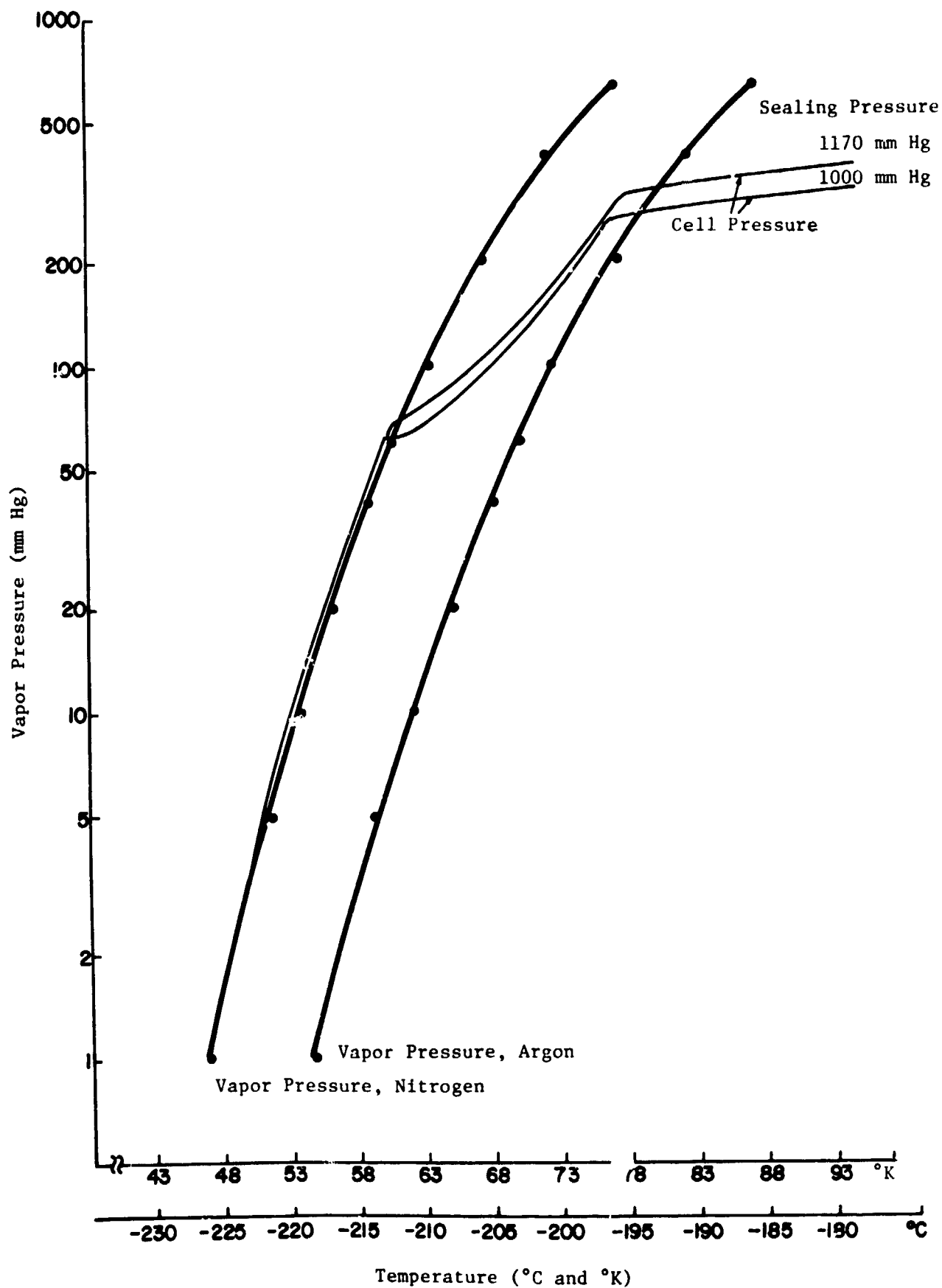


Figure 3. Vapor Pressure of Argon and Nitrogen, and Test Cell Pressure as a Function of Temperature

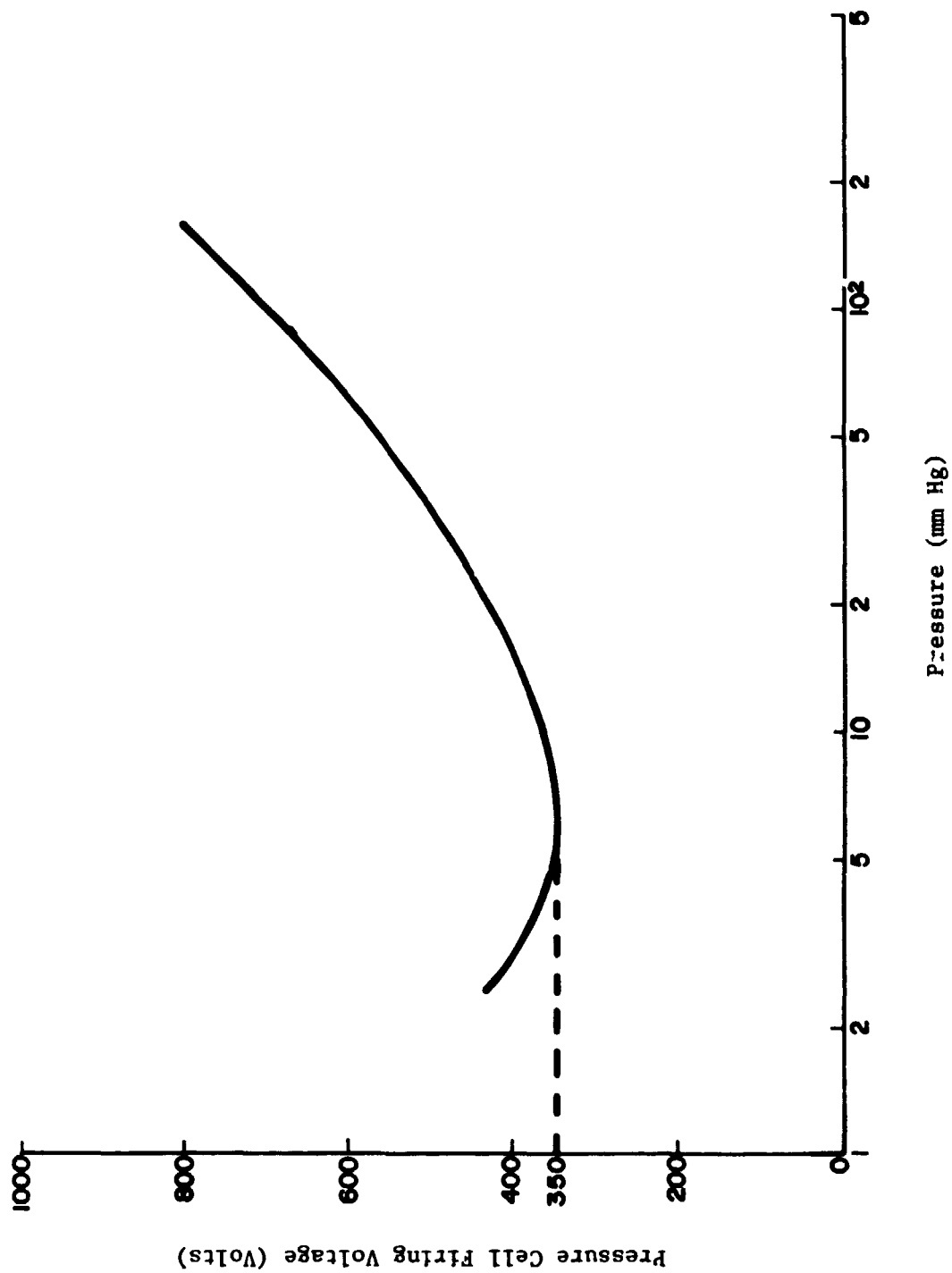


Figure 4. Worst-Case Paschen Characteristic

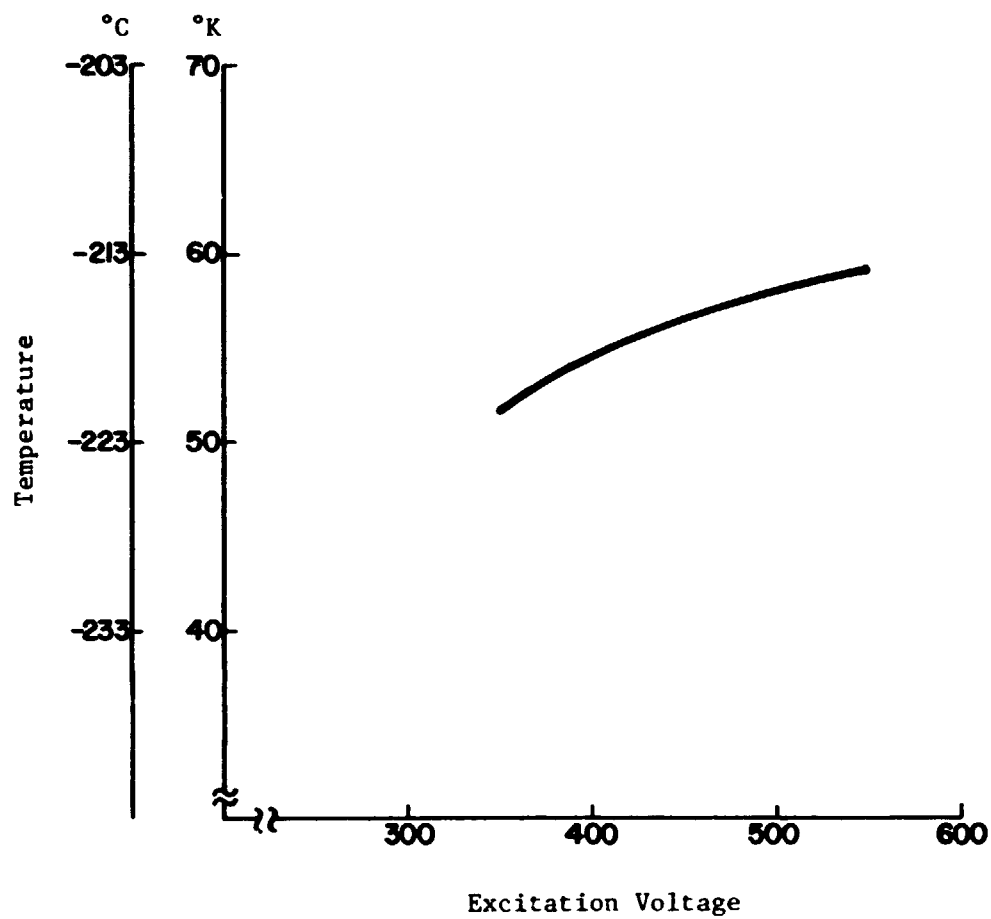


Figure 5. Temperature at Which Failure Occurs in a Sealed Cell Due to Gas Condensation as a Function of Excitation Voltage

Conclusions

From the results of the experiments described herein, and irrespective of the difference between the test cell and cells on board Pioneer 10 and Pioneer 11 (Earth's gravity, for example), it is concluded that the Pioneer pressure cells will fail at a temperature between the temperatures of LN_2 and LHe . The failure mode will be extraneous firing events due to decreasing pressure (discontinuous density) in the cells as the gas liquefies. The temperature at which failure occurs is relatively independent of the sealing pressure and the sealing temperature, and is only slightly dependent on the excitation voltage. The failure temperature is estimated to be 51°K at 350 volts excitation and increases to 59°K at 550 volts excitation. If one can assume that the pressure panels on a spacecraft are at approximately the same temperature, the panels will all begin to fire at approximately the same time. Consequently, the onset of the failure may be recognizable by an apparent "slow leak" in both data channels. Once the panels passed through the "liquefying temperature," and firings ceased, they may or may not fire again as a result of a meteoroid penetration, depending upon the dynamics of the solid-to-gas phase transition.

PIONEER MDE ELECTRONICS EQUIPMENT

Description of Apparatus and Procedure

A flight-quality, MDE electronic unit was tested at low voltage-low temperature conditions to determine conditions under which the electronic unit would not function properly. The flight-quality test unit was located in an environmental test chamber and connected to a modified ground support equipment (GSE) unit designed to exercise the MDE unit. The modification provided for supplying a variable dc voltage to the MDE unit as a simulated input from the spacecraft rather than a fixed 28 Vdc supply. Figure 6 is a block diagram of the test apparatus. The MDE was located in an environmental test chamber in order that the test temperature could be controlled. Other components were external so as not to be stressed by the cold temperature. The GSE provides for completely exercising the MDE electronic unit. It supplies a logic input to turn the MDE power converter ON, a nominal 28 Vdc to operate the MDE converter, two word gates, and bit shift inputs. It reads the two output words and displays contents of the MDE counters as parallel bits. It simulates transducer interface circuitry inputs serially to each of the twelve MDE interface circuits, and provides for bypassing the MDE transmission gate time delay feature to facilitate testing the MDE unit. The time delay feature can also be exercised with the GSE.

The 28 Vdc power supply internal to the GSE was disabled to provide for varying the nominal 28 Vdc to the MDE electronic unit. An external, constant 28 Vdc supply was substituted to supply the GSE load; an external, variable supply was substituted to supply the MDE load. These supplies are evident in Figure 6. The MDE power converter output voltage to the pressure cells was routinely monitored with a null voltmeter in order not to load this high impedance source.

The experimental procedure was as follows. The MDE temperature was set to a selected test temperature by incrementing the test chamber controller by 5°F at 5 minute intervals. When a selected temperature was reached, it was held constant for a period of one hour to allow the MDE temperature to stabilize. Following temperature stabilization, the GSE was used to completely exercise the MDE. With the variable supply set at a selected voltage, the GSE was used to simulate meteoroid hits (inputs due to pressure cell firings) to advance both MDE counters through a complete cycle. The MDE transmission gate inhibit feature was removed (by a GSE switch) to facilitate this test. Subsequent to this test, the transmission gate inhibit feature was returned to normal, and the MDE was monitored as multiple "hits" were generated in the GSE. Normal operation was observed when only a single event registered in each counter. This test procedure was repeated for increasingly lower input voltages (0.5 volt increments) until the MDE failed to complete a successful test. At each failure, the failure mode and voltage were recorded.

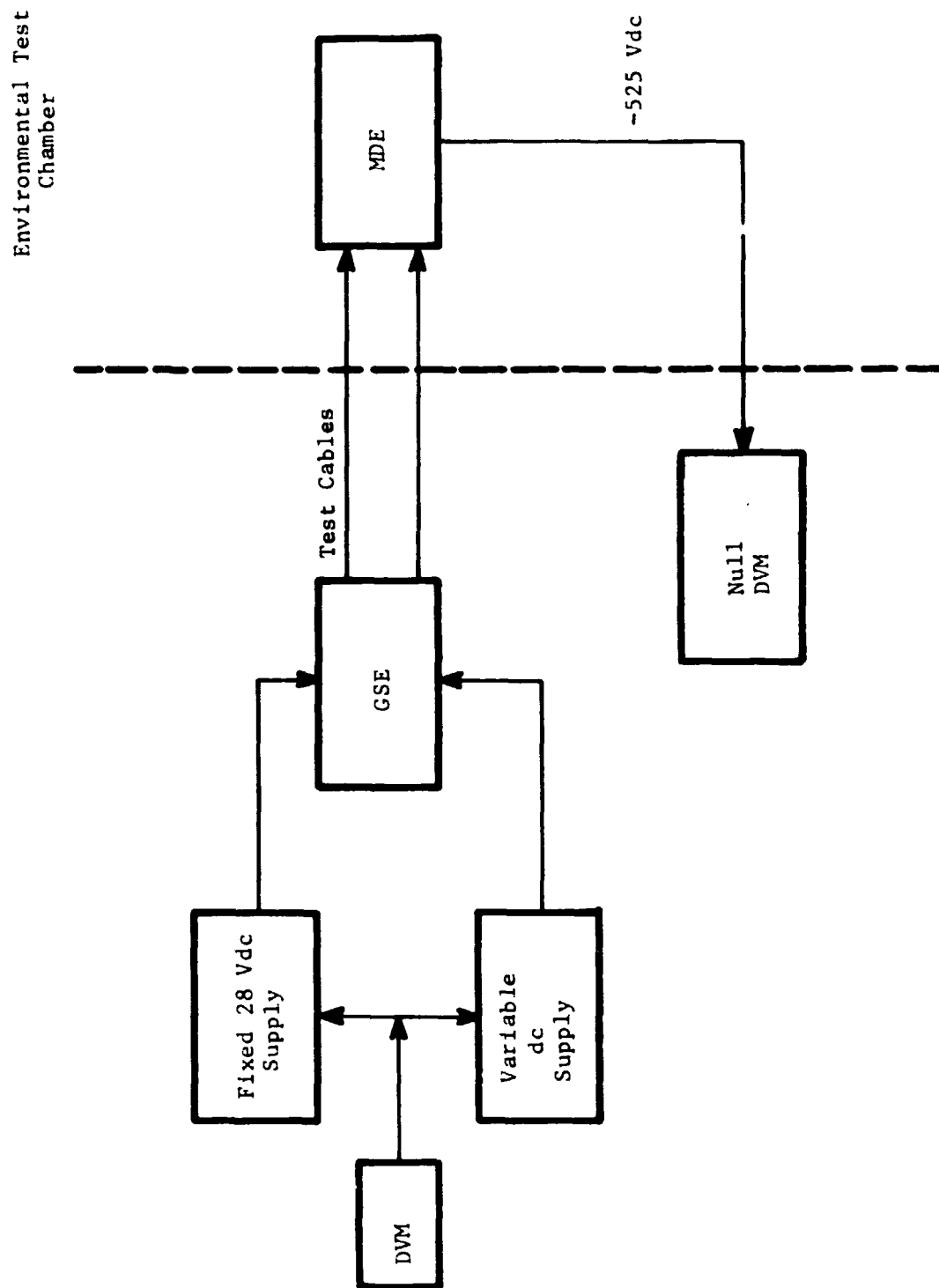


Figure 6. Block Diagram of the MDE Electronic Unit Test Apparatus

Following an MDE failure at a set temperature, the variable dc supply was increased to 28 volts, and the MDE converter voltage output to the pressure cells was recorded as a function of MDE excitation voltage at the set temperature.

Experimental Results

MDE Electronic Unit. - The results of the low voltage-low temperature experiments on the MDE electronic unit are summarized in Figure 7 where voltages corresponding to successful and unsuccessful tests are identified for several test temperatures. (The dashed line in Figure 7 will be discussed in a subsequent paragraph.) At -58° F, for example, all elements of the electronic unit were observed to function normally at 22 volts MDE excitation, but the MDE failed to function normally at 21.5 volts excitation.

The following failure modes were observed during these tests. The most frequent failure mode was a failure of the GSE to indicate the output of one or both of the MDE counters. When the excitation voltage was increased, however, the GSE did indicate the original content of the counters plus any additional hits inserted manually at the low voltage condition. This indicates that the failure is most likely in the level converters (Fairchild DTUL9041) interfacing the parallel to serial converters in the MDE with the GSE.

A second failure mode observed and concluded to be similar to the first was the following. While one channel (No. 2) alternately advanced six counts and remained constant for six counts as "hits" were simulated, the other channel (No. 1) continuously read zero. This failure mode changed to become identical to the first if the excitation voltage was lowered slightly (e.g., 0.1 volts) and disappeared if the voltage was increased slightly. This is concluded to be due to the failure of only one of the two level converters.

A third failure mode, observed at lower temperatures, was an intermittent failure of the MDE to register a hit. This failure mode could result from any of a number of logic element failures in the MDE OR gates, transmission gates, or event counters.

A fourth failure mode was observed but was traced to the GSE rather than the MDE. With multiple (more than six) GSE "hits" generated in the manual mode, one counter continued to advance one count for each "hit" generated. This apparent failure was concluded to be a malfunction of the GSE only in the Auto Sequence mode.

MDE Converter Pressure Cell Output Voltage. - The MDE converter pressure cell output voltage was observed to be a linear function of the MDE excitation voltage (variable dc supply) and relatively independent of temperature. These results are illustrated in Figure 8 where the MDE converter pressure cell voltage is plotted as a function of the excitation voltage, and

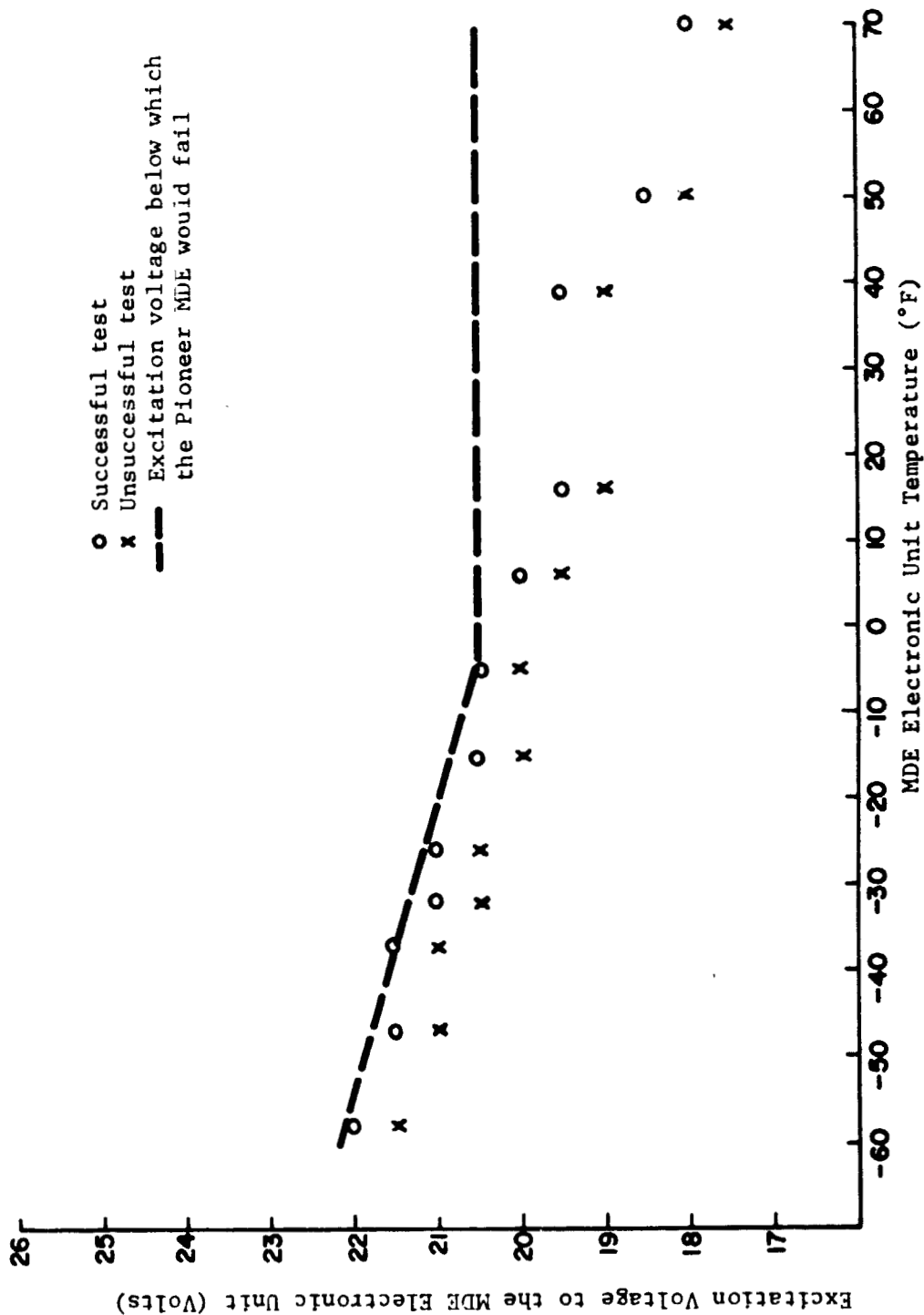


Figure 7. Temperature-Voltage Profile Corresponding to a Failure of the Pioneer MDE

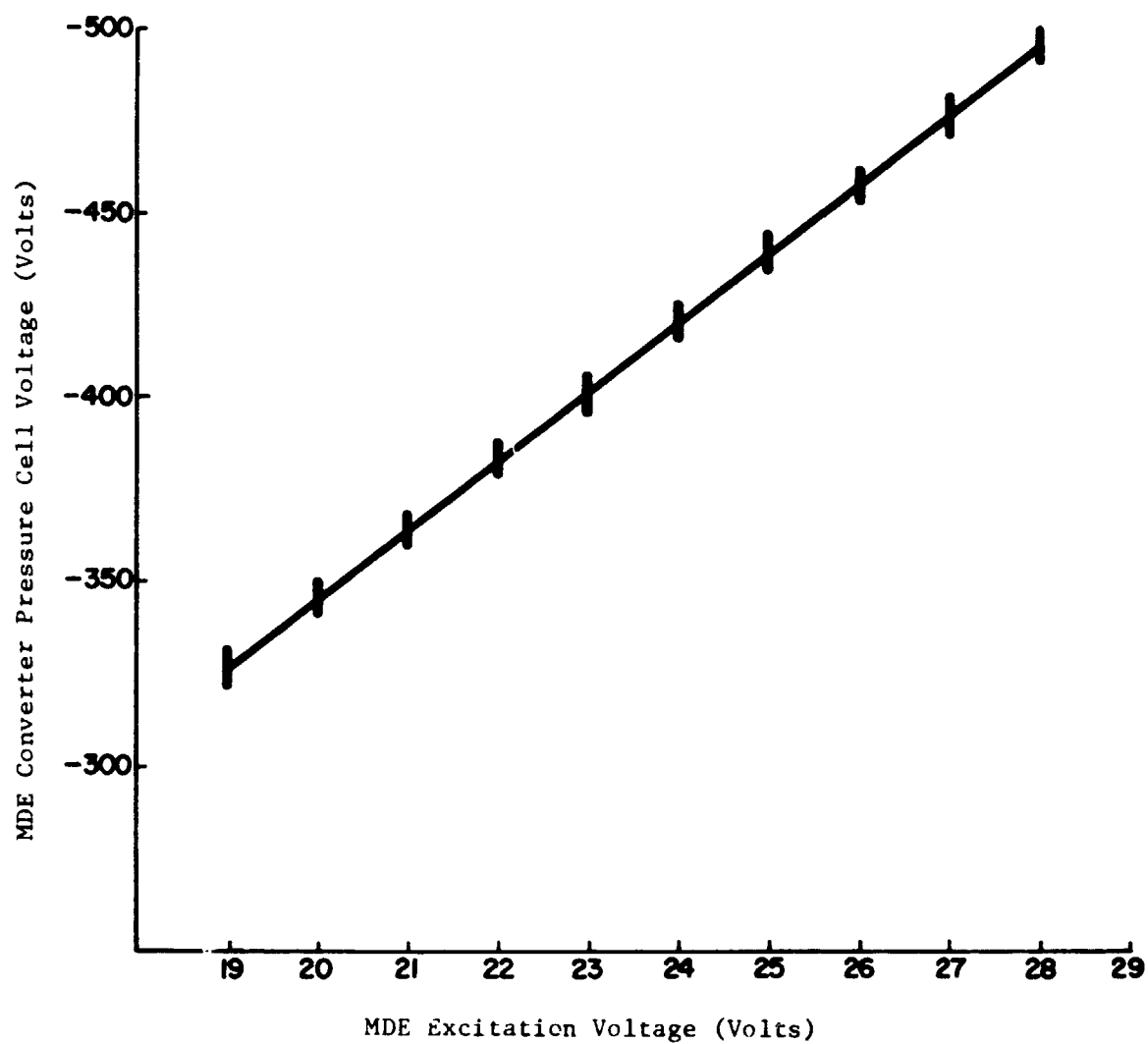


Figure 8. MDE Converter Pressure Cell Voltage as a Function of MDE Excitation Voltage

temperature is a parameter. The vertical bars connect the maximum and minimum pressure cell voltages at a given excitation voltage as the temperature was varied from +70°F to -58°F. The straight line was drawn somewhat through the middle of the vertical bars. These plots show the converter pressure cell voltage to be a linear function of the excitation voltage (with a slope of 18.7 volts per volt) and reasonably independent of temperature.

Since the minimum firing voltage of the MDE pressure cells at LHe temperature is between 300 and 350 volts, it is concluded that the converter pressure cell voltage output will be adequate for MDE excitation voltages down to approximately 20.5 volts.

Conclusions

It is concluded that the Pioneer MDE will fail if the excitation voltage goes below 20.5 volts because the voltage supplied to the pressure cells by the MDE converter will be inadequate to fire a penetrated cell. At temperatures below -5°F, the MDE will fail at higher excitation voltages because of MDE electronic unit failures. An electronic unit temperature-excitation voltage profile corresponding to failure is shown in Figure 7 as a dashed line.

CONCLUSIONS

This report has considered three factors which potentially can result in a failure of the Pioneer MDE. First, low temperatures at the pressure cell location can reduce the pressure in the cells until firings occur in the unpenetrated cells. The temperature at which this failure mode occurs is slightly dependent on the excitation voltage to pressure cells. Second, low excitation voltage to the Pioneer MDE electronics unit from the spacecraft can cause a reduction in the voltage supplied to the pressure cells to a value such that a penetrated cell would not fire. Third, low excitation voltage to the MDE can result in a failure of the MDE electronic unit to function. The voltage at which this failure occurs is a function of the MDE electronic unit temperature.

The conclusions relative to the pressure cell characteristics at low temperatures are based upon the experimental observation of pressure cell failures as the temperature of a test cell was repeatedly changed between room temperature and LHe temperature, the minimum voltage of the cells Paschen characteristic at LHe temperature, the assumption of a worst-case Paschen curve based upon earlier LN₂ temperature results, and a theoretical analysis of the cell pressure as a function of temperature. These results show the temperature at which failure will occur to be relatively independent of the sealing pressure, sealing temperature, excitation voltage, and exact locus of the Paschen curve. Consequently, although the experimental observations were based upon experiments with a single test cell, the conclusions herein should be applicable to all cells. The conclusions relative to the MDE electronic unit are based upon experiments with a single flight-quality unit. They should be valid for other flight-quality MDE units because the characteristics of the population of digital components in a given MDE unit should not differ significantly from other units. (The two channels in the MDE unit tested, for example, yielded almost identical results.)

It is concluded that the Pioneer MDE experiment will fail if the pressure cell temperature reaches or goes below 59°K. (It may not fail until it reaches 51°K if the excitation voltage to the cell is also reduced (see Figure 5), but 59°K is a reasonable worst-case value.) The failure mode will be firings in unpenetrated cells. It will also fail if the excitation voltage to the MDE electronic unit goes below 20.5 Vdc, regardless of the temperature of the MDE unit, because the MDE converter will no longer supply adequate voltage to fire a penetrated pressure cell. If the temperature of the MDE electronic unit goes below -5°F, the MDE unit will fail at excitation voltages above 20.5 Vdc. The dashed line in Figure 7 defines the MDE electronic unit temperature and excitation voltage combinations that will result in a failure of the MDE experiment.

References

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